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Effects of Nanosecond Pulsed Nd:YAG Laser Irradiation on Dentin Resistance to Artificial Caries-Like Lesions

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Background and Objective: **Previous investigations have demonstrated improved enamel caries resistance after laser irradiation. In this study, effects of nanosecond pulsed Nd:YAG laser irradiation on crown/root dentin susceptibility to caries-like lesions were investigated.**
Study Design/Materials and Methods: **Extracted human molar teeth were irradiated using a Q-switched nanosecond pulsed Nd: YAG laser. All teeth except controls were irradiated at: fluence, 1 or 5 J/cm^2; spot size, 3 mm; and then subjected to demineralization. Measurements of caries lesion depth using scattering light microscopy and SEM were performed.**
Results: **Lesion depth measurements did not differ significantly between controls and irradiated samples (*P* < 0.01), but SEM results showed some irradiation-induced alterations on crown and root dentin surfaces. Irradiated surfaces were partially melted, with sometimes narrowed or occluded tubules.**
Conclusion: **No consistent caries-protective effect of Q-switched nanosecond pulsed Nd:YAG laser irradiation on crown and root dentin was determined, but laser-induced morphological changes were observed. Lasers Surg Med 20:15–21, 1997.**

Key words: artificial caries-like lesion; demineralization; dental; Nd:YAG laser; scattering light microscopy; tooth

INTRODUCTION

Alterations in enamel caries resistance have been observed after irradiation with the ruby laser [1]. Since that time other lasers, such as the Nd:YAG, CO_2, or argon laser have also been used to enhance caries resistance in enamel [2–4]. Of these, the Nd:YAG laser was reported to be the most effective [5], even though some difficulties were experienced in achieving homogeneous results. The Nd:YAG laser has also been used for a wide range of other dental applications, including root planing [6], altering fibroblast attachment [7], apical sealing [8], treatment of hypersensitivity [9], removal of smear layer [10], soft tissue surgery [11], and ablation of hard tissue [12].

Laser systems operate in various modes, such as continuous wave, pulsed, chopped-wave, and Q-switched. One purpose of using these different modes is to minimize the rise in tissue temperature within the target area [13]. The Nd: YAG laser has been used in various modes to alter caries resistance in enamel [14]. Laser-induced changes in dentin caries-resistance have

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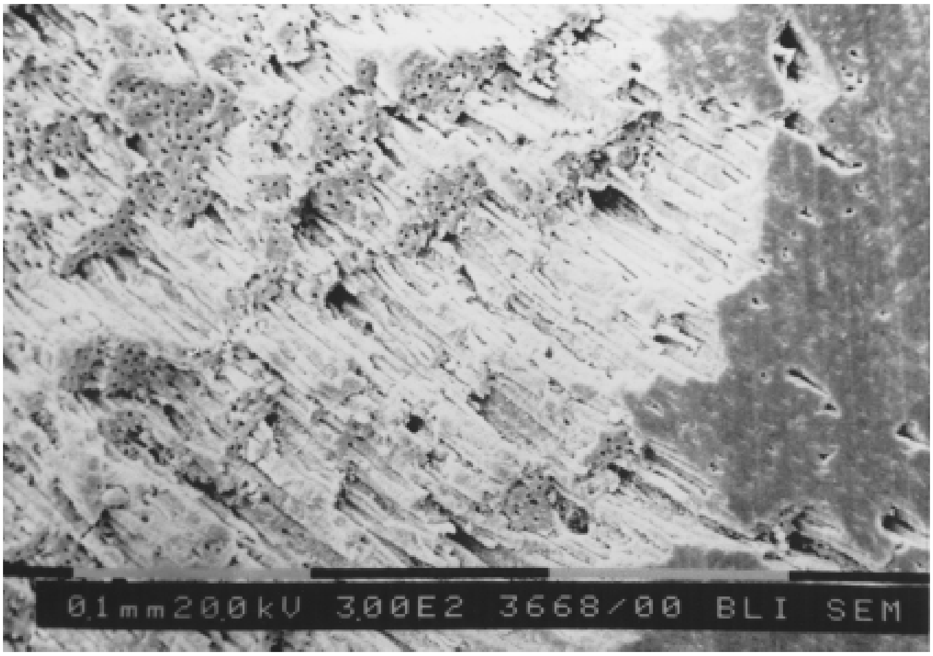


Fig. 1. Micrograph showing irradiated dentin at 5.4 J/cm^2. The left side was irradiated, and the right side was non-irradiated. Magnification is ×300. Bar represents 0.1 mm.

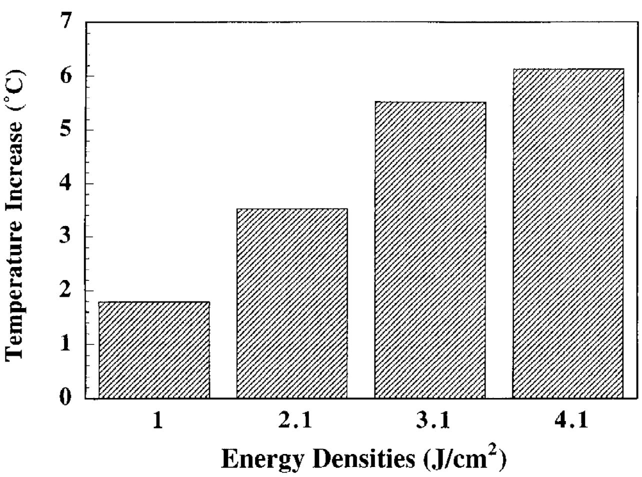


Fig. 2. The relation of temperature increases to energy densities. Tooth was horizontally bisected, and enamel was removed. Crown dentin was used for this experiment. Dentin thickness measured 1.7 mm.

also been investigated [15–17]. However, the thermal effects of this laser on the tooth must be considered. An intrapulpal temperature rise as small as 5.5°C can cause irreversible pulp damage [18]. In previous investigations, heat from irradiation with the Nd:YAG laser at continuous wave or long pulsed settings was often found to cause melting of the intertubular dentin [19]. Due to the proximity of heat-sensitive pulpal tissues to the dentin, it is important to minimize any temperature increase in dental hard tissue during irradiation. Thus, significant temperature increases in dentin can give rise to concerns regarding pulpal thermal damage. The Q-switched Nd:YAG laser system with nanosecond pulses may well offer significant advantages with regard to pulpal heating due to its short pulse duration and high peak powers.

The purpose of this study was to investigate the effects of Q-switched Nd:YAG laser irradiation with nanosecond pulses on crown and root dentin ablation, microstructure, and caries resistance characteristics. Thermal safety thresholds were also determined.

MATERIALS AND METHODS

Part I: Determination of Ablation Effects and Thermal Safety Threshold

Sample preparation. Twelve extracted human teeth showing no clinical sign of caries or decay were stored in demineralized water with 0.01% (w/v) thymol, and longitudinally bisected with a low speed saw (Isomet, Buehler, IL). Any residual pulp tissues were removed manually. The samples were fixed in a clamping device during irradiation.

Laser device and laser irradiation. To determine the range of structural modifications to

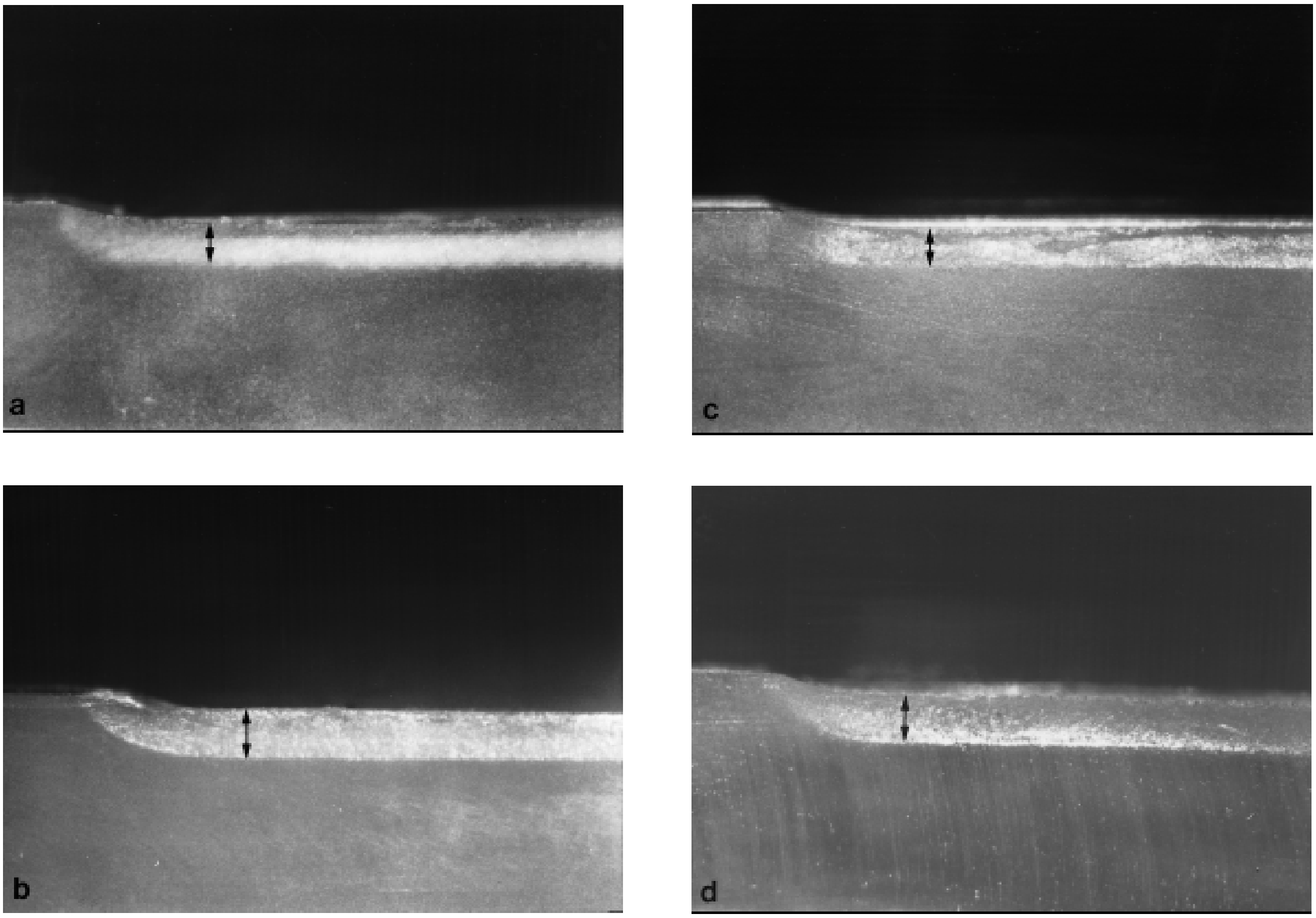


Fig. 3. Photographs of scattering light microscope results showing crown control (**a**) and irradiated samples at 1 J/cm^2 (**b**); and root control (**c**) and irradiated at 5 J/cm^2 (**d**). Distances between two arrows were measured. Magnification is ×64.

dentin, preliminary studies were performed using a Q-switched nanosecond pulse duration Nd:YAG laser (Medlite, Continuum Biomedical, Inc., Livermore, CA). This laser emits at a wavelength of 1064 nm and uses an articulated arm delivery system with a focusing handpiece. The pulse width is varied pulse to pulse 5 to 10 nsec, and the laser was used at energy densities (E_D) ranging from 2.7 to 28.0 J/cm^2 and a spot size of 3 mm. In this investigation, one pulse of laser irradiation was used on each sample. Therefore, fluence and energy density values are identical throughout this article.

SEM. After laser irradiation, samples were dehydrated in a graded series of aqueous ethanol (30, 50, 70, 90, 100% ethanol) for 10 minutes at each concentration, mounted on stubs using colloidal silver liquid (Ted Pella, Redding, CA) and gold coated on a PAC-1 Pelco advanced coater 9500 (Ted Pella). Micrographs of the dentin were taken on a Philips 515 (Mohawk, NJ) SEM.

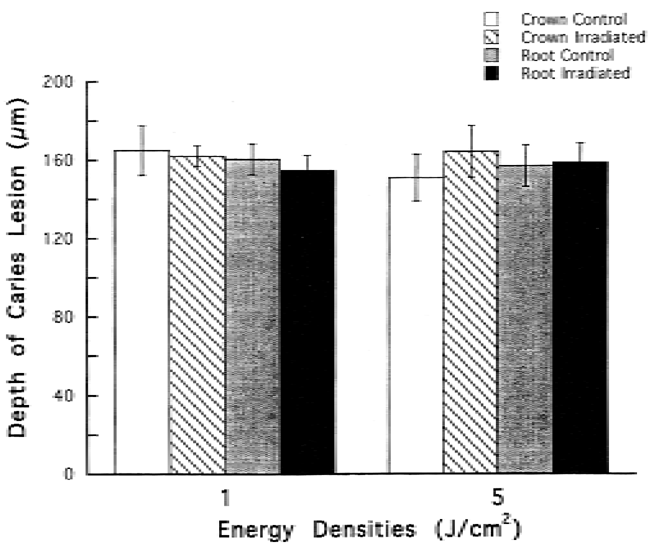


Fig. 4. The relation of depth of caries-like lesion to energy densities of 1 or 5 J/cm^2. Each value is measured at six points, and expressed as the means and standard error of the means.

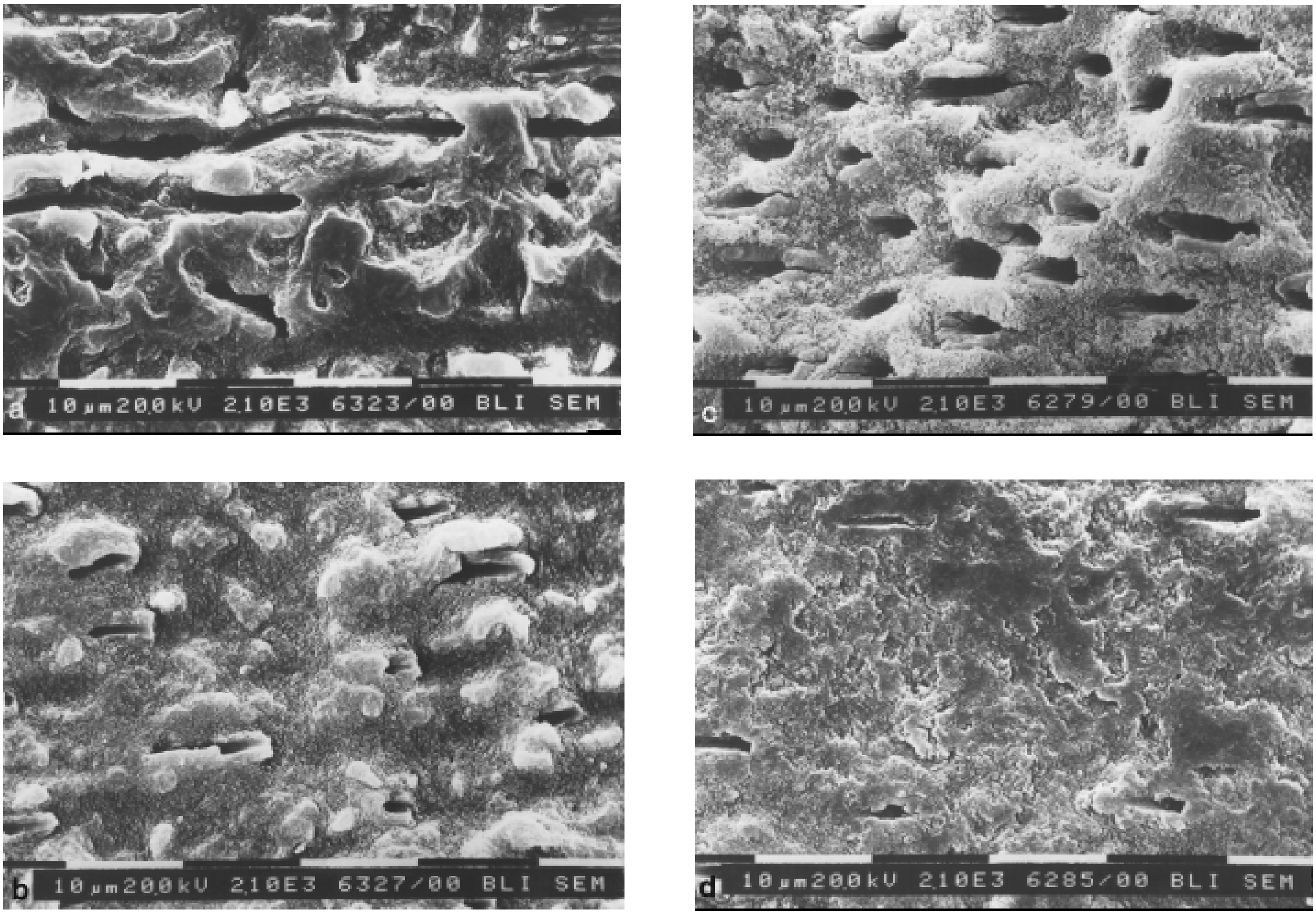


Fig. 5. Micrographs showing crown dentin of control (**a**) and laser treated (1 J/cm^2) samples (**b**) crown dentin of control (**c**) and laser treated (5 J/cm^2) samples (**d**), root dentin of control (**e**) and laser treated (1 J/cm^2) samples (**f**) and root dentin of control (**g**) and laser treated (5 J/cm^2) samples (**h**). Dentin tubules appear narrowed or closed, and dentin is melted partially on irradiated samples compared to control samples. Magnification is ×2,100. Bar represents 10 μm.

Thermal measurements. Enamel and cementum were removed from eight teeth with a high speed turbine and scaler, and then cut horizontally in half. A thermocouple (1.25 mm dia., Omega, Stamford, CT) was inserted from the apical aperture to contact snugly the root canal wall without gel. The outside tooth surface was irradiated with the beam impinging perpendicularly at the parameters described above.

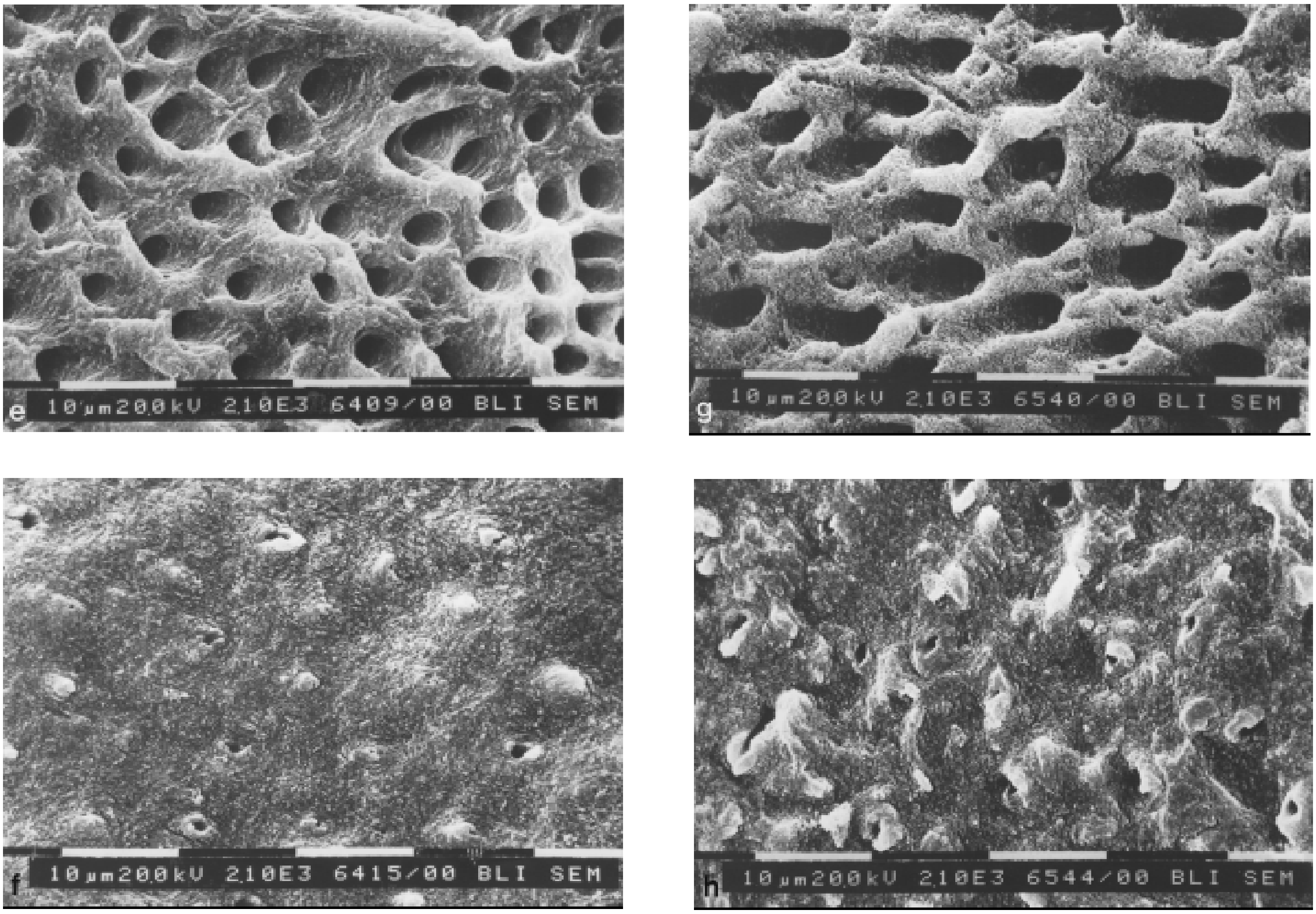
Measured values (mV) were converted to temperature (Celsius).

Part II: Irradiation Effects on Artificial Caries-Like Lesion

Sample preparation. Thirty-six extracted human teeth showing no clinical sign of caries or decay were selected and stored in demineralized water with 0.01% (w/v) thymol. The teeth were longitudinally bisected, and embedded in acrylic resin (Buehler, IL). The surfaces were polished using metallurgical apparatus (Buehler) with carbimet paper discs (grits 240, 320, 400, 600) (Buehler) and Metadi diamond suspension (1, 3, 6 micron) on a polishing cloth (Buehler). After polishing, each surface was covered with acid resistant vanish, leaving four 2–3 mm windows on the cut dentin surface.

Laser irradiation. Using a Q-switched nanosecond pulsed Nd:YAG laser (1064 nm), all teeth except the control group were subjected to irradiation at the following parameters: E_D of 1 or 5 J/cm^2 and spot size of 3 mm.

Artificial caries-like lesions. All samples were subjected to a demineralization solution for 14 days. The demineralization solution contained 0.1M lactic acid, 0.2mM methylene diphosphonic acid (MHDP) at pH4.8 and 0.01% thymol [20]. After demineralization, these teeth were then lon-



Figs. 5e–h.

gitudinally bisected again. On one half of each sample, scattering light microscope profiles were performed, while SEM was performed on the other half. An U60-2 light microscope (Olympus, Tokyo, Japan) was used with an Intralux 100HL (Volpi, Urdorf-Zurich, Switzerland) as a scattering light source. Six measurements were taken at arbitrary locations each time on each sample to determine depths of caries-like lesions. Means and standard error of means were computed. Statistical analyses were performed by Student's t-test (two-tailed).

RESULTS

Part I: Determination of Ablation Effects and Thermal Safety Threshold

Figure 1 shows SEM images of dentin irradiated at energy densities of 5.4 J/cm^2. There were some grossly observable changes in dentin. SEM results demonstrated microstructural damage at energy densities $\geqslant$5.4 J/cm^2, and at like energy densities, damage was greater with increasing pulse frequency. In order to avoid duplication of results, SEM results at lower energy densities are shown under Part II.

Figure 2 shows one representative result of the thermocouple measurements. In the thermal investigation, a maximum increase of temperature exceeding 5.0°C was measured at energy densities >2.0 J/cm^2. From these results, in order to remain within the range of useful microstructural alterations and below the threshold of thermal damage, our main investigation was performed at energy densities <2.0 J/cm^2. Additionally, an energy density of 5.0 J/cm^2 was used to investigate potential effects that can be achieved at higher energy level.

Part II: Irradiation Effects on Artificial Caries-Like Lesion

Figure 3 (a,b) shows light microscope images of crown dentin of control samples and specimens irradiated at 1 J/cm^2. Figure 3 (c,d) shows light

microscope images of root dentin of control samples and irradiated specimens at 5 J/cm^2. There is no clear difference between the control and irradiated samples in either crown or root dentin. The results of measurements of caries-like lesion depths using scattering light microscopy are shown in Figure 4. Lesion depth ranged from 123.7 to 170.9 μm in irradiated samples and from 116.7 to 176.1 μm in control specimens, but there was no significant difference between the two groups ($P < 0.01$), or between samples irradiated at 1 or 5 J/cm^2 ($P < 0.01$). Figure 5 shows SEM images. Fig. 5 (a,b) depicts results in crown dentin of control and samples irradiated at 1 J/cm^2; (c,d) depicts results in crown dentin of control and samples irradiated at 5 J/cm^2; (e,f) depicts results in root dentin of control and samples irradiated at 1 J/cm^2; and (g,h) depicts results in root dentin of control and samples irradiated at 5 J/cm^2. SEM results show some alterations on the surfaces of irradiated crown and root dentin. The surfaces were partially melted, and some dentin tubules were closed or narrowed. A moderate morphological effect was observed within this range of laser parameters.

DISCUSSION

A number of publications exist concerning laser effects on enamel, but far fewer reports have been published on laser effects in dentin. Dentin lies in a closer proximity to the pulp than enamel and heat is conducted quickly to the pulpal tissue. The Q-switched mode with nanosecond pulse duration offers the advantage of minimizing potential pulpal temperature increases due to the short pulse durations delivered. However, to date no reports exist by other researchers concerning the effects of Q-switched Nd:YAG laser irradiation on dentin.

As a preliminary investigation into the effects of this device, approximate threshold values for ablation, thermal, and microstructural damage to dentin were determined. Energy densities $\geqslant$5.4 J/cm^2 were found to cause outright ablation of tooth substance. In other reports, higher average energy densities were identified as the ablation threshold, perhaps due to the much lower peak powers produced by the longer-pulsed devices used in those studies [6,10,16].

In our main investigation, after demineralization, no clear difference between lesion depths in control and irradiated samples was determined using scattering light microscopy. Lesion depth ranged from 123.7 to 170.9 μm in irradiated samples and from 116.7 to 176.1 μm in control specimens, but there was no significant difference between the two groups ($P < 0.01$). Scattering light microscopy is an extremely useful technique for documenting lesion progression in hard tooth substance [21], and the results obtained in our investigation with this technique are paralleled by measurements obtained using microhardness techniques, where we were also unable to determine a significant protective effect of nanosecond pulsed Nd:YAG laser irradiation (submitted for publication).

Using SEM, the microstructural effects of artificially induced demineralization were clearly evident in all samples. After demineralization, surfaces of control samples were rough, and dentin tubules were open. In contrast, surfaces of irradiated samples after demineralization appeared partially melted and smoother than the control samples, and some dentin tubules were narrowed, or occluded. According to previous reports [15,22], Nd:YAG laser irradiation of dentin with pulse durations longer than those used in this investigation caused the surface to melt, occluded dentin tubules, and also produced visible calcification structures. No such calcifications, however, were observed in our study. This is probably due to the different parameters used. In our investigation, only a single pulse of laser irradiation was used at low energy densities. The long-duration irradiation in the continuous wave or long-pulsed mode used in most other investigations would induce far higher temperature rises in target tissues.

From our preliminary study, intrapulpal temperature increases occasionally exceeded 5.5°C during irradiation at energy densities of 2.0 J/cm^2. However, duration of the temperature increase induced by a pulse of Nd:YAG laser irradiation was very short (less than 2 seconds). According to Zach and Cohen [18], temperature increases exceeding 5.5°C for 5–20s can cause irreversible changes in the pulp. Thus, the temperature increases measured in our study appear to lie below the threshold of pulpal damage. However, in this investigation single pulses of laser irradiation were used. Before application to the clinical situation, the cumulative thermal effects of repeated pulses of laser energy at various frequencies need to be determined.

In conclusion, we were unable to detect any significant caries-preventive effect of nanosecond pulse duration Nd:YAG laser irradiation at moderate pulse energy parameters on crown and root

dentin. However, a range of microstructural effects was observed.

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